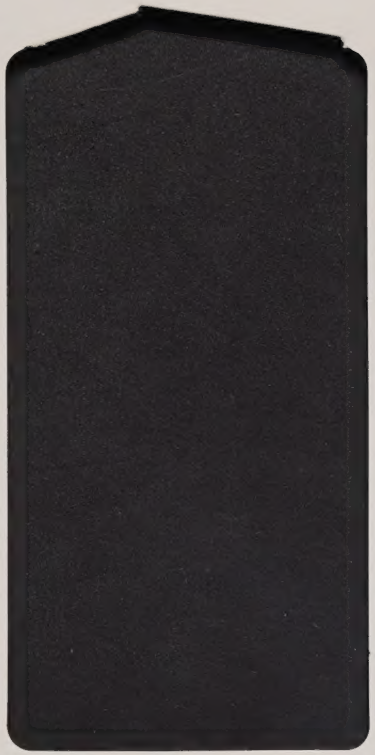
PRELIMINARY COPY

INSTRUCTION MANUAL

MODEL 160

DIGITAL MULTIMETER

KEITHLEY INSTRUMENTS, INC.



INSTRUCTION MANUAL

MODEL 160 #163

DIGITAL MULTIMETER

KEITHLEY INSTRUMENTS, INC.

OPERATING PROCEDURE

MODEL 160

DIGITAL MULTIMETER

The attached operating procedure is supplied to permit earliest possible delivery of this Model 160 to you. It will be followed by a preliminary and later a final instruction manual.

Please return the warranty registration card as we use it to obtain your name and address when sending these manuals.

If you have further questions, please contact your Keithley Representative or the Sales Service Department.

Product Literature Department

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TABLE OF CONTENTS

Section	Page
SPECIFICATIONS	ii
1. GENERAL DESCRIPTION	1
2. OPERATION	4
3. CIRCUIT DESCRIPTION	10

TABLE 1.

Specifications

AS A DC VOLTMETER

RANGE: ±1 microvolt per digit to ±1000 volts full scale in seven decade ranges. 100% overranging on all except the 1000-volt range.

ACCURACY: ±0.1% of reading, ±1 digit on all ranges.

INPUT RESISTANCE: 10 megohms on the 10-millivolt and higher ranges, 1 megohm on the 1-millivolt range.

AC REJECTION:

NMRR: Greater than 80 dB above one digit for a voltage of line frequency or twice line frequency on the most sensitive range, decreasing to 60 dB on the 100-millivolt and higher ranges. 1000 volts peak-to-peak maximum.

CMRR: Greater than 120 dB above one digit at dc and 40 to 100 Hz ac. 500 volts dc, 100 volts peak-to-peak ac maximum.

SETTLING TIME: Less than 2 seconds to rated accuracy.

MAXIMUM OVERLOAD: 1000 volts continuous input on 1-volt to 1000-volt ranges. 1000 volts momentary, 300 volts continuous on lower ranges.

AS A DC AMMETER: (Model 160 only)

RANGE: ±0.1 nanoampere per digit to ±1 ampere full scale in eight decade ranges. 100% overranging on all ranges.

ACCURACY: ±0.2% of reading, ±1 digit on all ranges.

INPUT RESISTANCE: 100 kilohms on the 0.1-microampere range, decreasing to 0.1 ohm on the 100-milliampere and 1-ampere ranges.

NMRR: 60 dB above one digit for a current of line frequency or twice line frequency.

MAXIMUM OVERLOAD: 50 times full scale continuous on all ranges up to a maximum of 3 amperes.

AS AN OHMMETER: (Model 160 only)

RANGE: 0.1 ohm per digit to 1000 megohms full scale in eight decade ranges. 100% overranging on all ranges.

ACCURACY: ±0.3% of reading, ±1 digit, ±0.1 ohm on the 100-ohm to 1-megohm ranges, decreasing to ±10% on the 100-megohm range. The 1000-megohm range is intended for relative resistance measurements only (±50%).

VOLTAGE ACROSS UNKNOWN: 100 millivolts at full scale, 1.5 volts maximum into an open circuit.

MAXIMUM OVERLOAD: 20 volts momentary, 1 volt continuous.

GENERAL

ANALOG OUTPUT: ±1 volt dc at up to 1 milliampere for full scale input, 100% overranging on all ranges except the 1000-volt range.

POLARITY: Automatic.

ZERO STABILITY: ±0.3 microvolt/°C, ±2 microvolts/day after 1-hour warm-up.

OFFSET CURRENT: Typically less than 10 picoamperes.

ACCURACY STABILITY: ±0.01%/°C (±0.06%/°C on ohms). Accuracy (rated at 23°C ambient after a 30-minute warm-up) is maintained for at least 6 months.

DISPLAY: 3 digits plus 1 overrange digit; polarity and overload indication; 2 readings per second.

ISOLATION: Circuit ground to chassis ground: greater than 100 megohms shunted by less than 0.02 microfarad. Circuit ground may be floated up to ±500 volts with respect to chassis ground in the voltage and current modes.

POWER: 105-125 or 210-250 volts (switch selected), 50 or 60 Hz, 20 watts.

SECTION 1. GENERAL DESCRIPTION

1-1. GENERAL.

a. The Keithley Model 160 is a completely solid-state, line operated multimeter with the accuracy and convenience of a digital display. It has seven d-c voltage ranges from 1 millivolt full scale to 1000 volts full scale with 100% overranging on every range except 1000 volts. The Model 160 also measures from 100 nanoamperes full scale to 1 ampere with 100% overranging on each range. The ohms ranges are from 100 ohms full scale to 1000 megohms also with 100% overranging.

b. The Keithley Model 163 is a Voltmeter-Only version of the Model 160 Digital Multimeter. It has all the main features of the Model 160 except the ammeter and ohmmeter functions are deleted.

c. With the use of Keithley Model 1601 AC/DC Probe, a-c measurements can be made from 0.1 volt to 250 volts rms over a span of 45 Hz to 45 kHz. A probe-mounted switch provides convenient selection of a-c or d-c operation without disconnecting the probe.

1-2. FEATURES.

a. Accuracy is ±0.1% ±1 digit on any voltage range.

b. Input is protected for ±1000 volts continuous input on 1-volt to 1000 volt ranges. Rated at ±300 volts continuous input on 1 millivolt range.

c. Zero stability is ±2 microvolts/day after one hour warmup.

d. Single RANGE Control is designated in convenient engineering units.

e. Circuit low to chassis ground isolation permits safe off-ground measurements up to ±500 volts.

f. Instrument operates from either 50 or 60 Hz, 117 or 234 volt power.

g. Convenient recorder output is ±1 volt at 1 milliampere.

h. Model 1602 Digital Output Kit provides optional BCD Output.

1-3. APPLICATIONS.

The Model 160 is a general purpose instrument - used in Basic Research, Electronics Development, and Process Control.

1. In the Research Lab - When used with a suitable probe, transducer, or electronic circuit, Model 160 can be used to indicate digitally, volts, amps, or ohms, or through conversion, any physical parameter such as temperature, pressure, rpm, etc.

2. In Electronics Development Activity - Useable for basic electrical measurements of voltage, current, or resistance. Especially suited for in-circuit resistance measurements.

3. In Process Control Activity - Adaptable for OEM equipment where repetitive measurements are needed with analog or digital printout.

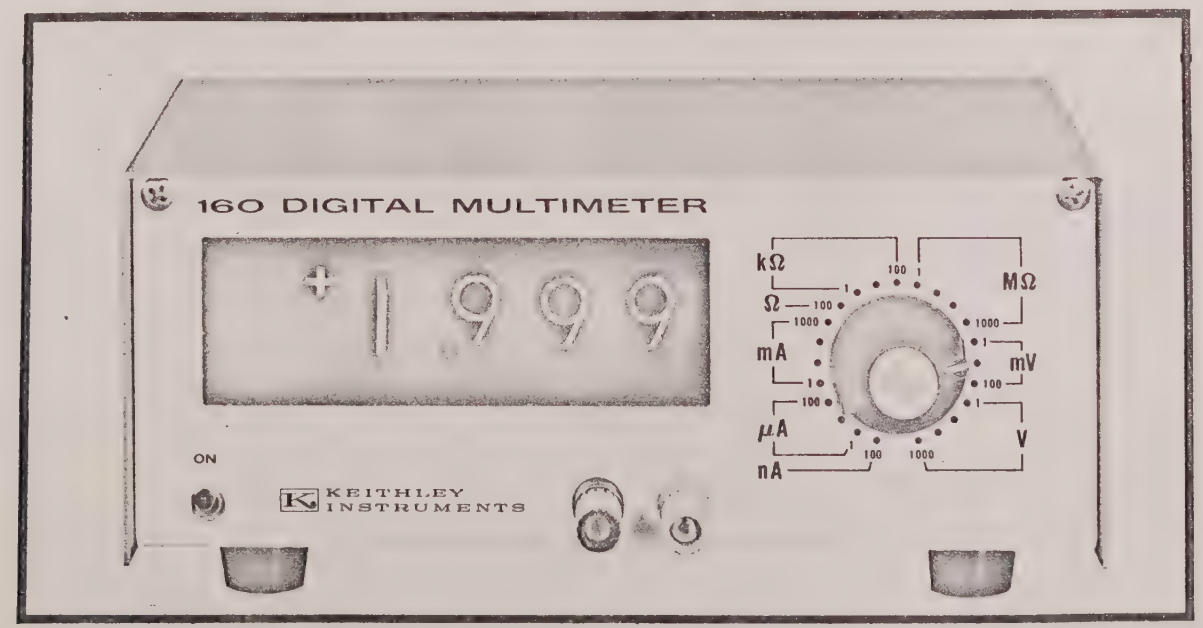

FIGURE 1. Model 160 Digital Multimeter - Front Panel

TABLE 1-2.

Front Panel Controls and Terminals. (Refer also to Figure 2). This Table briefly describes the function of the controls and terminals on the front panel. The paragraph indicated describes in detail the operation of the controls.

Control	Functional Description	Paragraph
Range Switch	Selects the full scale range of the function to be measured (volts, amperes, or ohms).	2-2
Power Switch	Controls a-c line power to instrument (ON/OFF).	2-2
High Terminal (Red)	Connects input high to signal source.	2-1
Low Terminal (Black)	Connects input low to signal source. Circuit low is connected to chassis ground when the rear panel LO Switch is in the GND position. For floating operation, set the LO Switch to FLOAT.	2-1, 2-9
±Display Indicator	Indicates polarity of the input signal.	2-5
Numerical Readout	Indicates magnitude of input signal.	2-5

TABLE 1-3.

Rear Panel Controls and Terminals. (Refer also to Figure 3). This Table briefly describes the function of the controls and terminals on the rear panel. The paragraph indicated describes in detail the operation of the controls.

Control	Functional Description	Paragraph
AC POWER Cord 50-60 Hz	Connects ac line power to instrument.	2-4
117V-234V Switch	Sets instrument for either 117 or 234V a-c line power.	2-3, 2-4
LO Switch	Sets the instrument for normal or floating operation. In GND position the chassis ground and circuit low are connected. In FLOAT the circuit low is not connected to chassis ground.	2-3, 2-9
ZERO Control	Fine zero adjustment. Screwdriver required for adjustment.	2-3, 2-4
OUTPUT Receptacle	Connects analog output to recording device. Output is ±1 volt d-c at up to 1 milliampere.	2-10

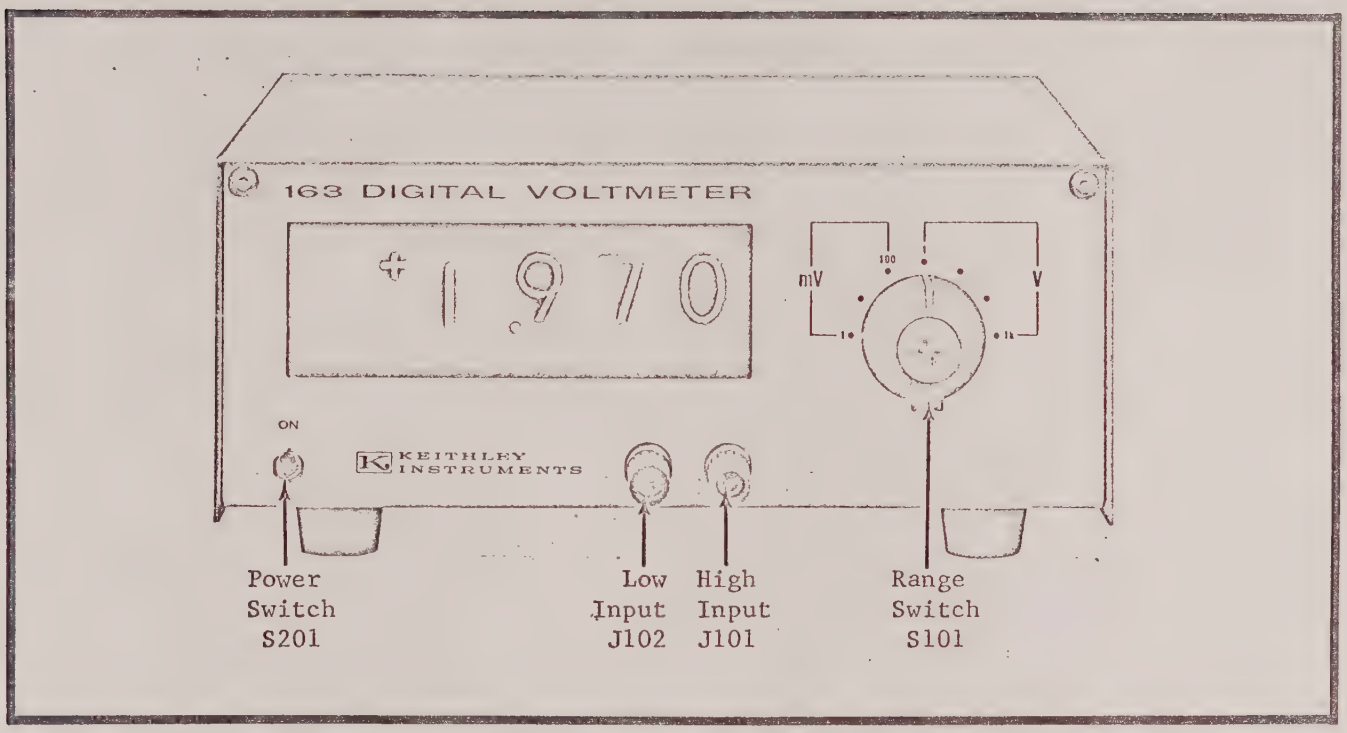

FIGURE 2. Model 163 Front Panel Controls and Terminals.

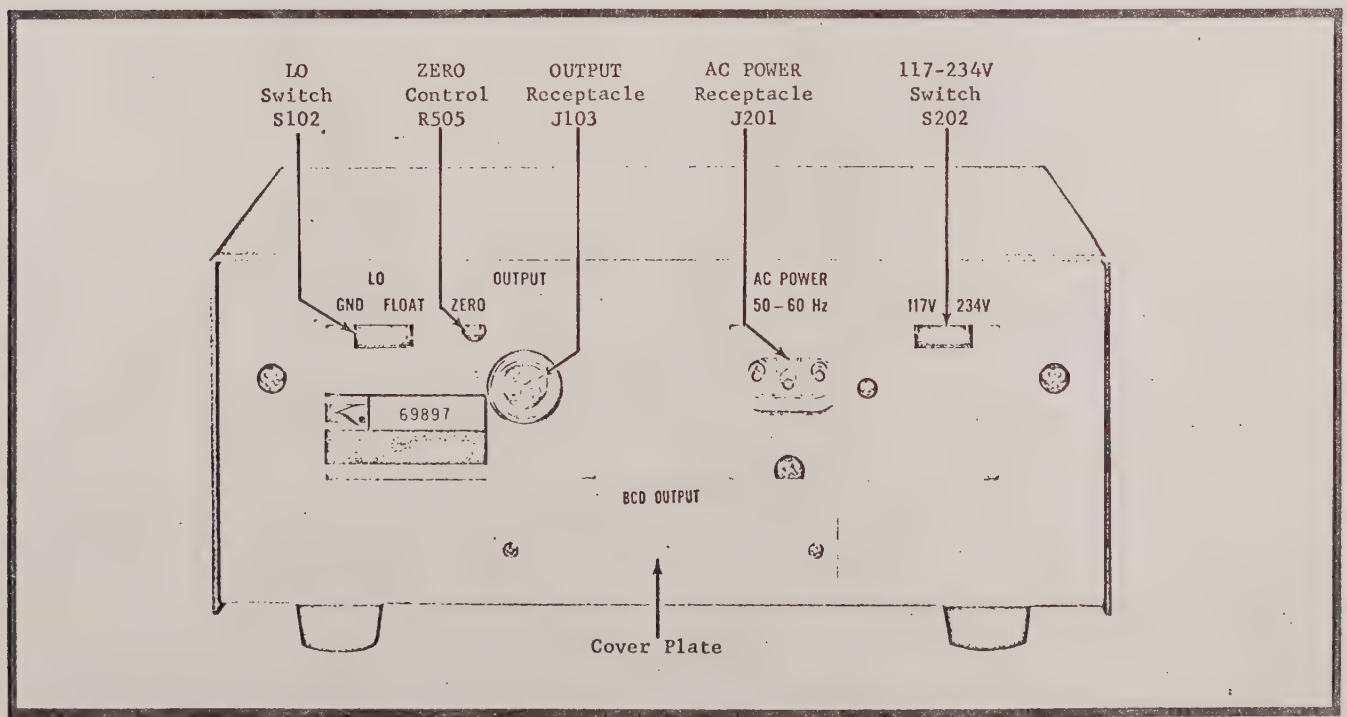

FIGURE 3. Model 160, 163 Rear Panel Controls and Terminals.

SECTION 2. OPERATION

2-1. INPUT CONNECTIONS.

a. Two binding posts are provided on the front panel for all input connections. The red terminal is the input high and the black terminal is the input low.

b. Voltage Measurements.

1. If the signal to be measured is 2 millivolts or less, use copper wires to connect the source to the input binding posts. This minimizes the error due to thermoelectric voltages that may develop due to temperature differences in the measurement circuit.

2. Use shielded input leads when source resistances are greater than 1 kilohm, or when long input cables are used. Connect the shield to earth ground. Also shield the source being measured whenever possible.

c. Current Measurements (Model 160 only). On the mA and μA current ranges, no special shielding precautions need be taken. However, on the 100 nanoampere range, shielded input leads are recommended.

d. Ohms Measurements (Model 160 only). Shielding of input leads and source are recommended for measurements on the 10 megohm through 1000 megohm ranges to prevent erroneous readings. Shielding is not normally required on the lower ranges.

2-2. FRONT PANEL CONTROLS.

a. The Power Switch is an ON/OFF toggle switch that controls the a-c line power to the instrument.

NOTE

The Power ON condition is shown by the lighted Polarity Indicator on the front panel display.

b. The Range Switch is a convenient single-T handle knob that controls the full scale range of the function to be measured.

1. The Range Switch dial is labeled in engineering units for voltage, current, and resistance. In any function sector, rotating the knob clockwise switches to the less sensitive range.

2. The voltage sectors of the Range Switch are designated in millivolts (mV) and volts (V) for full scale ranges from 1 millivolt to 1000 volts. A full stop at the highest voltage range prevents accidental overload of the current ranges.

3. The resistance (ohms) sectors of the Range Switch (Model 160 only) are designated in ohms (Ω), kilohms (KΩ), and megohms (MΩ) for full scale ranges from 100 ohms to 1000 megohms.

4. The current (amperes) sectors of the Range Switch (Model 160 only) are designated in nanoamperes (nA), microamperes (μA), and milliamperes (mA), for full scale ranges from 100 nanoamperes to 1000 milliamperes.

c. Digital Display. The digital display indicates the measured quantity with three full digits plus one digit for overrange.

2-3. REAR PANEL CONTROLS.

a. The LO Switch sets the instrument for normal or floating operation.

1. With the LO Switch placed in the GND position, the input low is connected to case ground for normal operation.

2. With the LO Switch placed in the FLOAT position, the input low is disconnected from case ground for floating operation. The input low can be floated up to ±500 volts dc.

NOTE

For maximum operator safety, make certain that the case is solidly connected to earth ground through the 3-prong line cord.

b. The 117-234 Volt Switch sets the instrument for either 117 or 234V rms a-c line power at 50 or 60 Hz.

NOTE

The front panel Power Switch is fused for either 117 or 234V operation. The fuses are installed on printed circuit board PC-254 and can be serviced by removing the top cover. The rear panel 117-234 Volt Switch connects either a 1/4 A (FU-33) or 1/2 A (FU-35) fuse for the selected line voltage.

c. The ZERO Control provides fine zero adjustment (usually required only for extreme changes of ambient temperature). This adjustment requires a screwdriver or similar tool.

2-4. PRELIMINARY OPERATING PROCEDURES.

a. Check the 117-234V Switch for the proper a-c line voltage.

b. Connect the line cord to either 117 or 234V a-c power line.

c. Short the input terminals with a low thermal connection - preferably a short copper wire or clip leads.

d. Set the front panel Range Switch to the 1 mV range.

e. Set the Power Switch to ON. Allow a 30 minute warmup period for measurements on 10 mV and lower ranges.

f. If the digital readout does not indicate zero, use the rear panel ZERO Control to adjust the instrument. Zero is indicated by continuously flashing ± polarity lights.

g. Set the Range Switch to voltage positions 1 mV to 1000V while checking the readout so that zero is indicated on all ranges.

NOTE

If there is an off zero reading on the 1 volt range, it will be necessary to adjust the CURRENT OFFSET ADJ on the underside of the chassis. Refer to Figure 13.

h. Set the Range Switch to Ohms positions 1000 MΩ to 100 Ω while checking the readout so that zero is indicated on all ranges (Model 160 only).

NOTE

If clips leads are used on the input terminals, an off zero reading may be indicated on the 100 Ω range since the last digit sensitivity is 0.1 Ω per digit.

i. Set the Range Switch to Amperes positions 1000 mA to 100 nA while checking the readout so that zero is indicated on all ranges (Model 160 only).

j. Remove the short circuit at the input terminals.

1. Volts Ranges. The instrument will normally read off zero on the 1 mV through 100 mV ranges because of sensitivity to random noise. The readout should remain at zero on the ranges 1V through 1000V.

2. Ohms Ranges (Model 160 only). All Ohms ranges should indicate a readout overload where all digits except a "1" in the overrange position are blanked. The + polarity indicator should also be lighted.

3. Amperes Ranges (Model 160 only). All current ranges should indicate a zero readout.

k. After the preceding checkout is made, the instrument should be useable for all measurements with no further adjustments necessary.

2-5. DIGITAL READOUT OPERATION.

a. Voltmeter Digital Readout.

1. When the Range Switch is placed in Voltage positions 1 mV through 1000V, the digital readout designates the actual voltage measured.

2. The Range Switch is designated in convenient engineering units, mV (millivolts) and V (volts) with the decimal point automatically positioned in the readout.

3. The full-scale voltage range is determined by the Range Switch. Refer to Table 2-1 for the full-scale voltage ranges available.

TABLE 2-1.

Full Scale Range Volts	Decimal Point Position	Engineering Unit
1×10^{-3}	.XXX	mV
1×10^{-2}	X.XX	mV
1×10^{-1}	XX.X	mV
1	.XXX	V
10	X.XX	V
100	XX.X	V
1000	XXX	V

4. The fourth readout (left most digit) permits an overrange display. Refer to Table 2-2. The largest reading that can be displayed using all four digit readouts is 1999. For an input greater than 1999, all readouts will be blanked except the overrange readout which will indicate a "1". The polarity (±) display indicator will remain lighted indicating the correct polarity. Thus the instrument will indicate correctly within specifications with no ambiguous overload display.

NOTE

The maximum momentary input voltage is ±1000 volts on any range.

TABLE 2-2.

Input Volts	Digital Readout	Engineering Unit
1.999×10^{-3}	1.999	mV
1.999×10^{-2}	19.99	mV
1.999×10^{-1}	199.9	mV
1.999	1.999	V
19.99	19.99	V
199.9	199.9	V
1000	1000	V

5. To remove the overload condition, change the Range Switch setting or decrease the input signal magnitude.

b. Ammeter Digital Readout (Model 160 only).

1. When the Range Switch is placed in Amperes positions 100 nA through 1000 mA, the Multimeter digital readout designates the voltage across a calibrated self-contained resistor. The Range Switch automatically selects the calibrated range resistor for current measurements from 1×10^{-7} to 1 ampere full scale.

2. The Range Switch is designated in convenient engineering units, nA (nanoamperes), μA (microamperes) and mA (milliamperes) with the decimal point

automatically positioned in the readout.

3. The full-scale current is determined by the Range Switch. Refer to Table 2-3 for the full-scale current ranges available on the Model 160.

TABLE 2-3.

Full Scale Range Amperes	Decimal Point Position	Engineering Unit
1×10^{-7}	XX.X	nA
1×10^{-6}	.XXX	μA
1×10^{-5}	X.XX	μA
1×10^{-4}	XX.X	μA
1×10^{-3}	.XXX	mA
1×10^{-2}	X.XX	mA
1×10^{-1}	XX.X	mA
1	XXX	mA

4. The overranging feature of the instrument permits 100% overrange with a 1999 maximum display using all four digits. An input greater than 1999 will cause a blanking of the three righthand readouts the same as for voltage measurements.

c. Ohmmeter Readout (Model 160 only).

1. When the Range Switch is placed in Ohms positions 100 Ω through 1000 MΩ, the Multimeter digital readout designates the voltage across the unknown resistor with a known current applied.

2. The Range Switch is designated in convenient engineering units, Ω (ohms), KΩ (kilohms) and MΩ (megohms) with the decimal point automatically positioned in the readout.

3. The full-scale resistance is determined by the Range Switch. Refer to Table 2-4 for the full-scale resistance ranges available on the Model 160.

TABLE 2-4.

Full Scale Range Ohms	Decimal Point Position	Engineering Unit
1×10^{2}	XX.X	Ω
1×10^{3}	.XXX	KΩ
1×10^{4}	X.XX	KΩ
1×10^{5}	XX.X	KΩ
1×10^{6}	.XXX	MΩ
1×10^{7}	X.XX	MΩ
1×10^{8}	XX.X	MΩ
1×10^{9}	XXX	MΩ

4. The overranging feature of the instrument permits 100% overrange with a 1999 maximum display using all four digits. An input greater than 1999 will cause a blanking of the three righthand readouts the same as for voltage measurements.

2-6. VOLTMETER OPERATION.

a. The instrument can be conveniently used for d-c voltage measurements from ±1 microvolt to ±1000 volts by connecting the source to the front panel binding post terminals.

b. Overload Recovery. The instrument will recover from 300-volt overloads within five seconds on the 1 mV range. Up to 1000 volts peak may be applied momentarily on any range without damaging the instrument.

c. Input Impedance. For 10 mV and higher ranges, a 1000 ohm source resistance will introduce only 0.01% error. To maintain rated accuracy on the 1 mV range, the source resistance should not exceed 100 ohms.

d. The instrument low terminal may be floated ±500 volts above CASE ground for voltage measurements. Refer to paragraph 2-9 for complete instructions.

e. The Model 1601 AC/DC Probe permits convenient a-c voltage measurements from 0.1 volt to 250 volts rms over a span of 45 Hz to 45 kHz. A probe-mounted switch provides convenient selection of a-c or d-c operation without disconnecting the probe. Therefore, the probe may be permanently attached since the probe provides straight through d-c operation with no degradation of performance.

2-7. AMMETER OPERATION (Model 160 only).

a. The Model 160 can be conveniently used for d-c current measurements from ±0.1 nanoampere to ±1 ampere with 100% overranging on all ranges.

b. Connections to the source are made as follows:

1. Connect the input high terminal to the source high potential.

2. Connect the input low terminal so as to place the Multimeter in series with the current to be measured.

c. Shielded cables are recommended for measurements on the 100 nA range since the Model 160 readout may be sensitive to low frequency noise.

d. The current accuracy is specified at the input terminals. Since the input voltage drop is 10 millivolts on all ranges except 1000 mA, the loading effects should be considered. Refer to Figure 4.

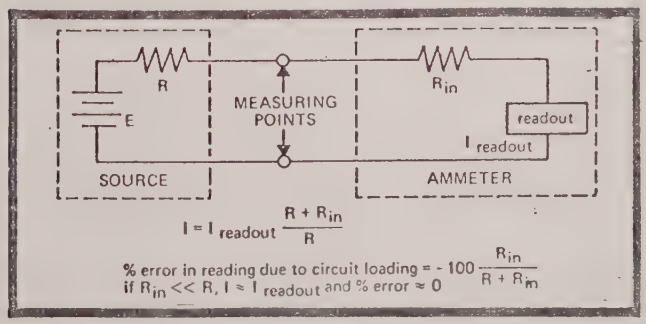

FIGURE 4.

e. The Model 160 low terminal can be floated ±500 volts above CASE ground for current measurements. Refer to paragraph 2-9 for complete instructions.

2-8. OHMMETER OPERATION (Model 160 only).

a. The Model 160 can be conveniently used for resistance measurements from 0.1 ohm to 2000 megohms by connecting the unknown resistor across the front panel binding post terminals.

b. Shielded cables are recommended for measurements on ranges 10 MΩ through 1000 MΩ to prevent erroneous readings.

c. Accuracy. Refer to Table 2-5.

TABLE 2-5.

Full Scale Range	Decimal Point Position	Accuracy of Typical Reading*
100 Ω	XX.X	±0.3% ±0.1 Ω
1 KΩ	.XXX	±0.3%
10 KΩ	X.XX	±0.3%
100 K	XX.X	±0.3%
1 M	.XXX	±0.3%
10 M	X.XX	±0.3%
100 M	XX.X	±10%
1000 M	XXX	±50%

*(±1 digit on all ranges.)

2-9. FLOATING OPERATION.

a. The low terminal can be floated ±500 volts above CASE ground by setting the rear panel LO Switch to FLOAT position.

b. When the instrument is used for off-ground voltage or current measurements, the low terminal is at floating potential. The instrument case ground should be connected to earth ground through the ground pin on the rear panel 3-prong AC POWER receptacle and line cord supplied.

NOTE

For operator safety, make certain that the instrument case is securely connected to earth or building ground. Connect to ground using the three-prong line cord or other solid electrical connection to the chassis.

2-10. ANALOG OUTPUT. The instrument has an analog output of ±1 volt at up to 1 milliampere for recording purposes. For off-ground operation, the analog ±1 volt OUTPUT should not be connected unless an external recorder is capable of floating at ±500 volts such as Keithley Model 370.

2-11. DIGITAL OUTPUTS AND EXTERNAL CONTROLS.

a. General.

1. The Model 1602 Digital Output Kit provides optional BCD outputs and controls.

2. Included is a 50-pin PRINTER/CONTROL Connector (receptacle) for mounting on the instrument rear panel.

3. An output buffer card plugs into a prewired connector on the chassis for either factory or user installation. Buffer card replaces PC-255 interconnecting card.

b. Output Codes and Levels.

1. The PRINTER/CONTROL Outputs are Binary Coded Decimal (BCD) Signals with 1-2-4-8 standard code.

2. The standard signal levels are as follows:

Output Logic "1" > +5 volts with less than 100 microamperes leakage.
Output Logic "0" < +0.5 volts with +50 milliamperes maximum allowable current.

3. The Buffer Stages utilize "Open Collector" output transistors. Therefore, the user must supply a pull-up resistor R and external voltage V_{EXT} for each buffered output. Refer to Figure 5.

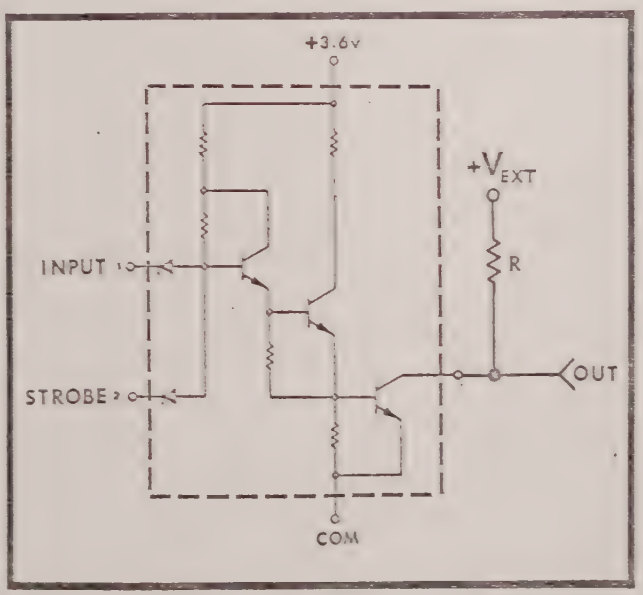

FIGURE 5.

c. Output Information.

TABLE 2-6.

Model 1602 Outputs

DIGITAL OUTPUT: BCD (1, 2, 4, 8) open collector logic (Motorola MC 858P) represents each of 3 digits, overrange digit, overload ("1"), polarity (+ = "1"), and decimal position (2 bits).

TIMING OUTPUTS:

Clock: Internal clock pulses (10 kHz count rate).

Count Interval: Logic "0" appears during count interval (i.e. pulse width is proportional to analog input signal).

Flag: Logic "1" appears for a 300 millisecond interval out of a conversion time of 500 milliseconds. No change in buffer storage is made outside this interval.

OUTPUT LOGIC LEVELS:

Output Logic "1": open transistor collector to ground with less than 100 microamperes leakage. +12 volts maximum allowable applied voltage.

Output Logic "0": transistor switch closure to ground with less than 0.5 volt saturation voltage. +50 milliamperes maximum allowable current.

REMOTE CONTROLS:

Strobe: Open circuit to ground inhibits all output lines from conducting (closure to ground enables conduction).

Hold: Closure to ground retains result of last conversion in both the output register and the display.

2-12. ACCURACY CONSIDERATIONS.

a. Noise Considerations. The limit of resolution in voltage and current measurements is determined largely by the noise generated in the source. Stray low-level noise is present in some form in nearly all electrical circuits. The instrument does not distinguish between stray and signal voltages since it measures the net voltage. When using the 1 mV and 10 mV ranges, consider the presence of low-level electrical phenomena such as thermocouples (thermoelectric effect), flexing of coaxial cables (triboelectric effect), apparent residual charges on capacitors (dielectric absorption), and battery action of two terminals (galvanic action).

b. Thermal EMFs. Thermal emfs (thermoelectric potentials) are generated by thermal differences between two junctions of dissimilar metals. To minimize the drift caused by thermal emfs, use copper leads to connect the circuit to the instrument. The rear panel ZERO control can be used to buck out a constant thermal offset voltage if necessary. The Keithley accessory Model 1483 Low Thermal Connection Kit contains all necessary materials for making very low thermal copper crimp connections for minimizing thermal effects.

2-13. SHIELDING.

a. The instrument provides attenuation of line frequency noise superimposed on an input d-c signal. However, care should be taken to minimize pickup by using shielded leads.

b. Magnetic pickup can be minimized by eliminating loops formed by the input leads. When using shielded leads, connect the shield to low at only one point in the circuit.

TABLE 2-7.
Model 1602 PRINTER/CONTROL Connector Pin Identification

Pin No.	Output	Function	Pin No.	Output	Function
1	1×10^0	Data	26	Common	---
2	2×10^0	Data	27	Common	---
3	4×10^0	Data	28	Blank	---
4	8×10^0	Data	29	10 KHz	Clock
5	1×10^1	Data	30	Blank	---
6	2×10^1	Data	31	Blank	---
7	4×10^1	Data	32	Blank	---
8	8×10^1	Data	33	Blank	---
9	1×10^2	Data	34	Blank	---
10	2×10^2	Data	35	Blank	---
11	4×10^2	Data	36	Blank	---
12	8×10^2	Data	37	Blank	---
13	1×10^3	Data	38	Blank	---
14	+ = Logic "1"	Polarity	39	Blank	---
15	1×10^0	Decimal Point	40	Blank	---
16	2×10^0	Decimal Point	41	Blank	---
17	Blank	---	42	Blank	---
18	Logic "1"	Overload	43	Blank	---
19	Blank	---	44	Vcc2	External Voltage
20	Logic "0"	Count Interval	45	Blank	---
21	Blank	---	46	Blank	---
22	Blank	---	47	Grounded	Hold
23	Logic "1"	Flag	48	Blank	---
24	Common	---	49	Grounded	Strobe
25	Common	---	50	Blank	---

FIGURE 6. TIMING DIAGRAM.

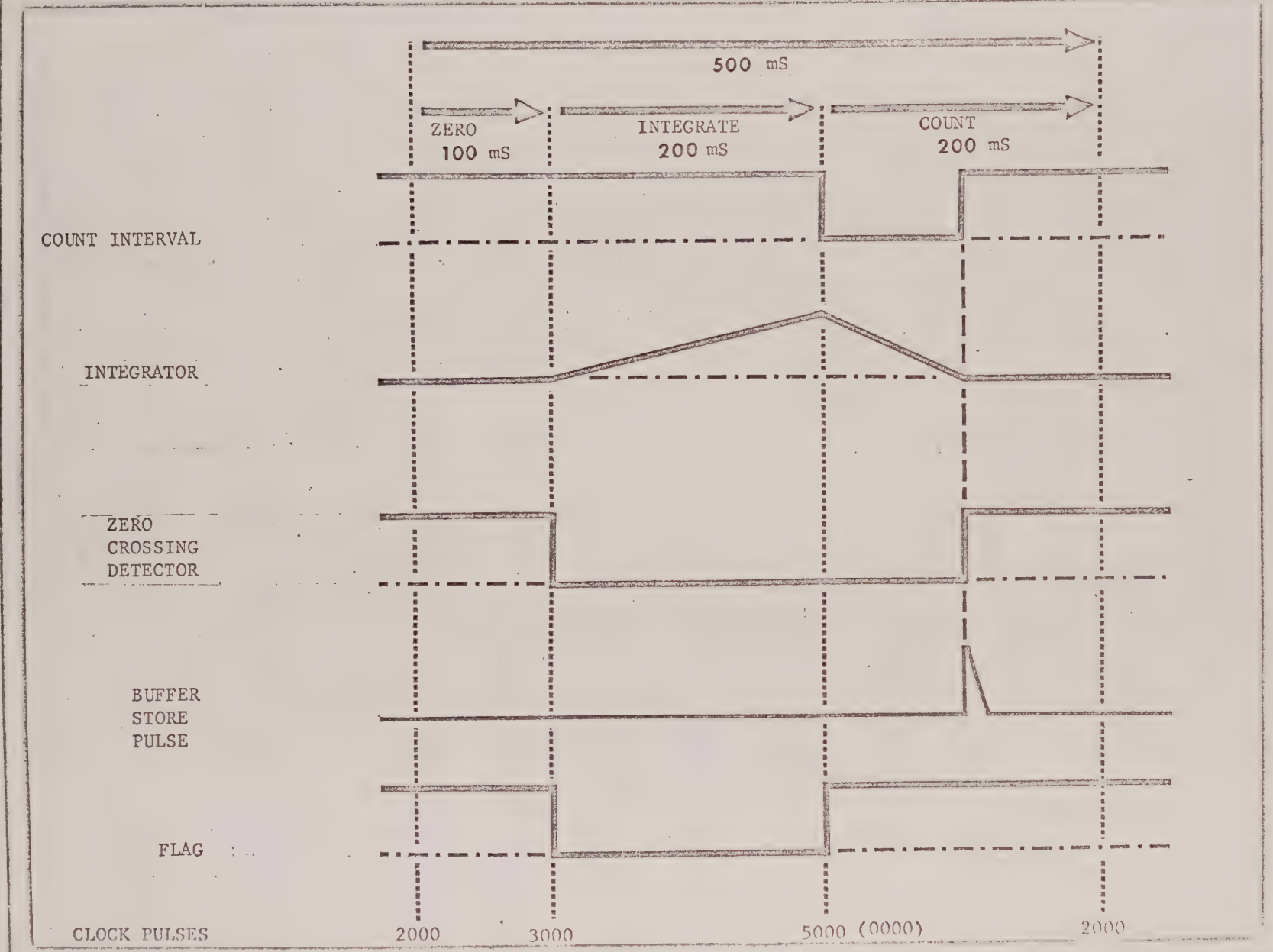

FIGURE 6. (Page 9)

SECTION 3. CIRCUIT DESCRIPTION

3-1. GENERAL.

a. The basic digital voltmeter consists of two sections packaged together in one chassis: an analog amplifier and an analog-to-digital converter.

b. The analog amplifier is a variable-gain chopper amplifier.

c. The analog-to-digital converter is a dual-slope integrating type converter with two readings/second conversion rate. A BCD output and external control options are available when used with the Model 1602 Digital Output Kit.

3-2. ANALOG AMPLIFIER OPERATION. The analog amplifier is shown in the simplified block diagram, Figure 7.

a. Voltage Amplifier Operation. The amplifier has a full-scale sensitivity variable from 1 millivolt to 100 millivolts. Above 100 millivolts the input signal is divided down to the 100 mV full-scale level. The signal flow path can be described as follows: An input signal applied at the Input High terminal is attenuated by a resistor divider. The signal is filtered and applied to a Modulator circuit. The a-c signal is then amplified and demodulated. A final variable gain d-c amplifier provides a d-c signal for the Analog output and A to D converter. The output is fedback to provide overall gain stability.

1. Input Resistor Divider. The input signal is attenuated by a divider network for RANGE Switch 1V, 10V, 100V and 1000V full-range positions.

2. Filter Network. The filter network provides a-c filtering for Normal Mode a-c noise.

3. Modulator Circuit. This circuit converts the low level d-c input to an a-c signal.

4. A-C Amplifier. This circuit uses negative feedback to provide gain accuracy and stability.

5. Demodulator Circuit. The demodulator is synchronized with the input modulator. It converts the amplified a-c signal to a d-c signal.

6. D-C Amplifier. This amplifier provides additional gain to drive the A to D converter and Analog recorder output.

7. Chopper Drive Circuit. This circuit generates the drive voltage for the mod-demod choppers.

NOTE

The circuit description for the ammeter and ohmmeter functions apply only for the Model 160 Digital Multimeter. Refer to Figure 8.

b. Ammeter Operation (Model 160 only). The instrument operates as an ammeter by detecting the voltage drop across a known shunt resistor. The sensitivity and resistor values are shown in Table 3-1.

c. Ohmmeter Operation (Model 160 only). The instrument provides a known constant current which is applied to the unknown resistance. The voltage output is proportional to the resistance measured.

3-3. ANALOG AMPLIFIER CIRCUITRY.

a. General. The circuits described in this section are located on the various sub-assemblies listed below and in Table 4-3 of Section 4.

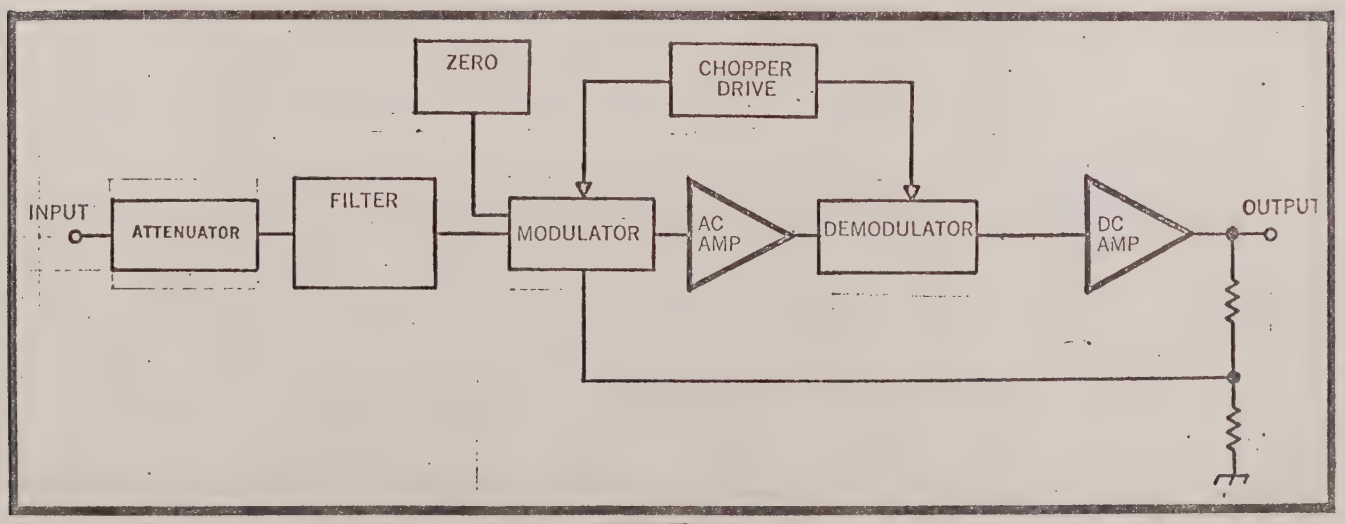

FIGURE 7.

TABLE 3-1.

Full Scale Range Amperes	Shunt Resistor Ohms	Voltage Sensitivity
1×10^{-7}	10^{6}	10 mV
1×10^{-6}	10^{4}	10 mV
1×10^{-5}	10^{3}	10 mV
1×10^{-4}	10^{2}	10 mV
1×10^{-3}	10	10 mV
1×10^{-2}	1	10 mV
1×10^{-1}	.1	10 mV
1	.1	100 mV

1. Mother Board, PC-254.

2. Analog Amplifier, PC-251.

3. Connector Board, PC-255.

b. Voltage Amplifier Circuit. The voltage amplifier circuit is composed of a chopper amplifier with fractional feedback. The feedback resistors are selected by the Range Switch so as to maintain low feedback current. The feedback network, composed of resistors R513, R516, R519 and R703, is formed from the output of the d-c amplifier to the low side of the modulator.

1. Input Resistor Divider. The chopper amplifier has a minimum gain of 10 and a full-scale output voltage of ±1 volt. Thus it is necessary to attenuate signals greater than 100 millivolts to prevent saturation of the chopper amplifier. The input attenuator resistors R101, R102, and R103 through R111 are switched by the Range Switch S101.

2. Filter Network. The a-c filter network provides a-c rejection at 60 Hz. The filter is a 2-section RC Lapper filter composed of resistors R501 and R502 and capacitors C501 and C502.

3. Modulator Circuit. The modulator circuit utilizes MOS FET chopper switches to provide low offset voltage and current, low input noise, and low drive power. A series-shunt chopper configuration maintains high input impedance. Transistors Q701 and Q702 form the chopper.

4. A-C Amplifier. The a-c amplifier is a low noise amplifier composed of transistors Q703 and Q704 and an integrated circuit QA702.

5. Demodulator Circuit. The demodulator utilizes an FET shunt switch which is synchronized with the input modulator. The FET Q705 switching action creates a rectified d-c signal with a large chopper frequency a-c component. Resistors R717 and R718 with capacitor C710 provide a filtering action of the demodulated signal.

6. D-C Amplifier. The d-c amplifier utilizes an integrated circuit QA703 to provide d-c gain and capability of up to 1 milliampere at the analog output.

7. Chopper Drive Circuit. The chopper frequency signal is derived from the Oscillator circuit. Transistors Q706 and Q707 provide opposite phase square waves used to drive MOS-FET chopper transistors Q701 and Q702. Transistor Q708 provides a demodulator drive signal for FET Q705 which is synchronous with the modulator drive signals. Flip-Flop circuits QA701A and QA701B divide down the 909.09 Hz from the oscillator by 4:1 for a chopper drive of approximately 227.3 Hz.

8. Zero Adjustment Circuit. This circuit provides

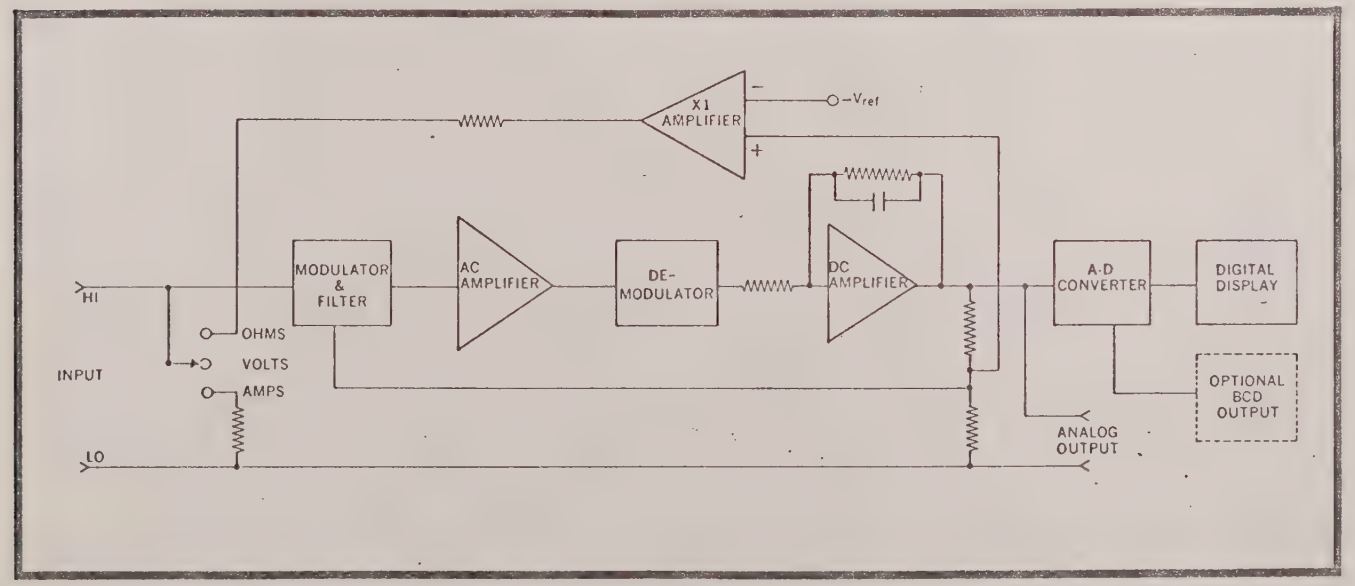

FIGURE 8.

limited adjustment of zero offset. It is composed of potentiometer R505 and resistors R503, R504, R506, R508 and R509.

c. Ammeter Circuit (Model 160 only). The instrument utilizes the chopper amplifier described above with various Range shunt resistors R116 through R122. The chopper amplifier functions as a voltage amplifier to provide an analog recorder output and drive for the A-to-D converter.

d. Ohmmeter Circuit (Model 160 only). The instrument provides a constant-current using a voltage reference amplifier and series resistor R. The reference voltage E limits the open-circuit voltage to 1.5 volts maximum. The voltage reference is composed of integrated circuit QA704 and reference diode D702.

3-4. ANALOG-TO-DIGITAL CONVERTER OPERATION.

a. General (refer to Figure 9 for a detailed block diagram of the A-to-D converter). The analog-to-digital converter uses a dual slope integration technique which has inherent line frequency noise rejection. The analog signal is applied to the integrator for 200 milliseconds which is an even multiple of the line frequency of 50 or 60 Hz. The analog signal is then removed from the integrator input. The voltage on the integrator is then driven to zero to complete the voltage-to-time conversion. The time interval to reach a "Zero Crossing" is counted and displayed on the "Digital Readout" in proportion to the original analog signal. Before the sequence is repeated, the integrator is rezeroed. (Refer to the Timing Diagram shown in Figure 6).

b. The A-to-D Converter is composed of eight major circuits.

1. Oscillator or Clock
2. BCD Counter
3. Program/Decoder
4. Integrator
5. Zero Crossing Detector
6. Buffer/Storage Register
7. Decoder/Driver
8. Numerical Readout.

c. Oscillator or Clock. The Oscillator produces pulses at a rate of 10 kilohertz for either 50 or 60 Hz operation.

d. BCD Counter. The BCD Counter counts the Clock pulses with a total range of 5000 counts. The Counter is composed of 4 individual counters designated 1, 10, 100, and 1000.

1. The "1", "10", and "100" counters have a capacity of ten counts each.

2. The "1000" counter has a capacity of five counts.

3. The total capacity of all four counters is 5000 counts.

e. Program/Decoder. The Program/Decoder circuit produces event commands to control the overall sequence of events for a complete A-to-D conversion.

TABLE 3-2.

Command	Function
2	ZERO
3,4	INTEGRATE
0,1	COUNT

f. Integrator. The Integrator circuit operation is composed of three periods (refer to Figure 6).

1. Zero Period. During this period the integrator amplifier is zeroed by a feedback rezeroing circuit as shown in Figure 10 . Switches S_a, S_b, and S_d are open to prevent integrator charging.

2. Integration Period. During this period switches S_b, S_c, and S_d are open. Switch S_a is closed to permit charging by the analog voltage for an even multiple of the line frequency.

3. Discharge Period. During this period, switch S_a is open to prevent further charging by the analog signal. Either switch S_c or S_d is closed to drive the Integrator voltage to zero. A reference current of opposite polarity to the input current is applied through either switch S_c or S_d. The Discharge Period ends when the Zero Crossing Detector circuit detects a zero Integrator output.

g. Zero Crossing Detector. The Zero Crossing Detector circuit provides a "High" or "Low" level output depending on the polarity of the detected input. Refer to Table 3-3 for a description of voltage outputs of the Zero Crossing Detector.

TABLE 3-3.
Zero Crossing Detector Output Levels.

M	N	B	C
0V	-0.5V	+1.5V	0V
0V	+3.5V	0V	+1.5V

h. Buffer/Storage Register. The Buffer/Storage Register is composed of "flip-flops" arranged to copy the states of the various BCD counters. The Buffer/Storage Register requires a Buffer Store command before any information can be transferred. The "flip-flop" circuits provide coded information for Decoder/Driver and the BCD outputs.

i. Decoder/Driver. The Decoder/Driver circuit decodes the BCD information from the Storage Register into ten-line decimal code. The Driver circuit then drives the proper numeral in each of the Numerical Readout tubes.

j. Numerical Readout. The Numerical Readout con-

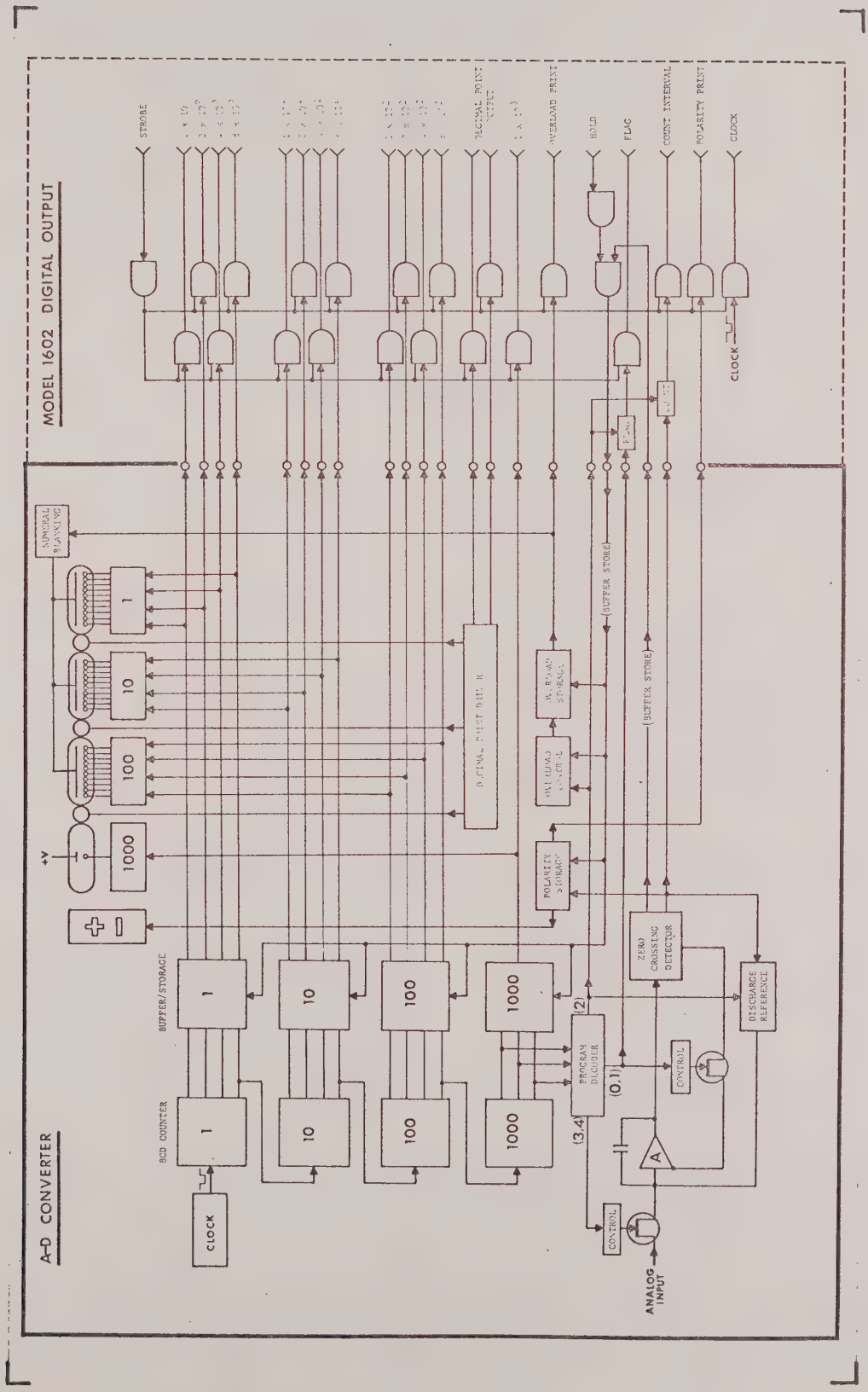

FIGURE 9. Analog-to-Digital Converter and Model 1602 Output Buffer

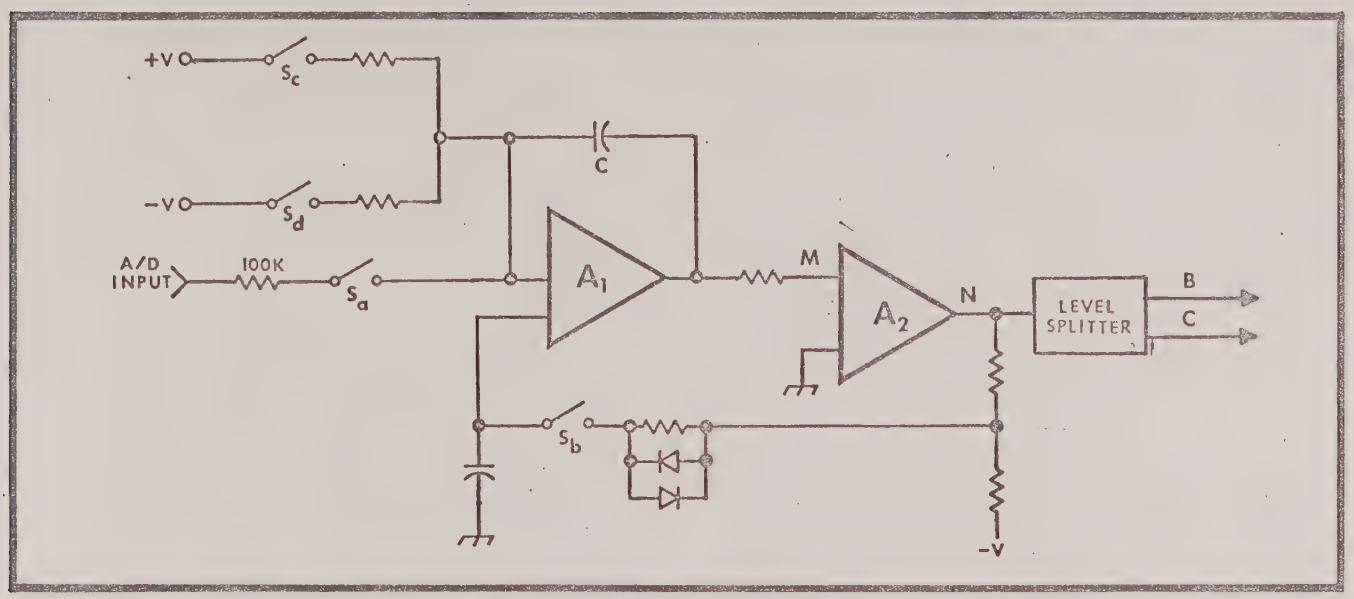

FIGURE 10. Integrator Block Diagram.

sists of four numerical indicators and one polarity indicator driven by the Decoder/Driver, Polarity and Overload Drivers.

k. Summary of Operation. The operation of the A-to-D Converter can be described by considering a typical conversion cycle.

1. The Clock provides pulses at a rate of 10 kilohertz.

2. The BCD Counter serves as a master timing control for the A-to-D conversion cycle. The timing is accomplished by the "1000" counter which has five coded states, namely 0, 1, 2, 3, and 4.

3. The Program/Decoder controls the sequence of commands based on the coded states from the BCD Counter. The decoded commands are described as shown in Table 3-2. The "2" command initiates the integrator ZERO period which removes any residual charge on the integrator capacitor. The "3,4" command initiates the INTEGRATE period which permits an integration of the analog signal. At the end of the INTEGRATE period, the "0,1" command initiates the COUNT period.

4. When the "3,4" command is given, the integrator is charged by the analog signal for a period of 200 milliseconds.

5. When the "0,1" command is given, the analog signal is removed and the integrator output is driven to zero by a reference current. The Zero Crossing Detector senses a zero crossing of the Integrator output and removes the reference current. The Detector provides outputs as shown in Table 3-3. The +1.5 volt levels are provided for control of the Integrator and Polarity Storage Register. A pulse command is also produced to initiate a Buffer/Store.

6. When the Buffer/Store command is given, the Buffer/Storage Register copies the BCD Counterstates at that instant of time. The BCD coded information in the Register is then available for the Decoder/Driver and external printout.

7. The Decoder/Driver decodes the Buffer/Storage output and drives the Numerical Readout for a digital display.

8. The conversion cycle is completed when the BCD Counter reaches 2000 counts and the Program/Decoder provides a "2" command to initiate a new conversion cycle.

3-5. ANALOG-TO-DIGITAL CONVERTER CIRCUITRY.

a. General. The circuits described in this section are located on the various sub-assemblies listed below and in Table 4-3 of Section 4.

1. Tube Board, PC-248
2. Integrator Board, PC-250
3. Oscillator Circuit, PC-254.

b. Oscillator Circuit. The Oscillator circuit is located on a portion of printed circuit assembly PC-254. Refer to schematic diagram P/N 24691E for this circuit. Transistors Q601 and Q602, capacitors C601, C602, and C603 and resistors R606 and R607 form an oscillator. Potentiometer R605 is used to provide internal screwdriver adjustment of the oscillator frequency. Transistor Q603 serves as an emitter-follower to reduce output impedance. The chopper drive is obtained by dividing down the oscillator frequency from 10 Kilohertz to 909.09 Hz using integrated circuit QA801, a 11:1 Divider circuit.

c. Tube Board. The Tube board contains portions of five major circuits: the BCD Counter, the Program/Decoder, the Buffer/Storage Register, the Decoder Driver, and the Numerical Readout.

1. BCD Counter.

a) The Decade Counters designated "1", "10", and "100" are composed of individual integrated circuit modules QA308, QA309, and QA310 respectively.

b) The "1000" Counter is composed of integrated circuit modules QA301A, QA302A, and QA302B.

2. Program/Decoder. This circuit is composed of gates QA304A, QA304C, QA305 (B, C, D, E, F) QA306A and QA307B.

3. Buffer/Storage Register. This circuit is composed of integrated circuit modules QA311, QA312, and QA313.

4. Decoder Driver. This circuit is composed of integrated circuits QA314, QA315, and QA316.

5. Numerical Readout. V301, V302, V303 are Readout Tubes for Units, Tens, and Hundreds respectively.

6. Other circuits contained on the Tube Board are described as follows.

a) Overrange Indicator Circuit. This circuit is composed of integrated circuit module QA301B, transistor Q301 and overload indicator DS301.

b) Polarity Indicator Circuit. This circuit is composed of transistors Q305 and Q306 and Polarity indicator module DS302.

c) Display Rate/Hold Circuit. Gates QA303 (A, B, C, D) and QA304B, QA306B, and QA307A provide capability for Display Rate and Hold functions when used with additional Output Buffer circuits.

d. Integrator Board. The Integrator Board contains portions of three major circuits: the Integrator circuit, the Zero Crossing Detector Circuit, and the Feedback Rezeroing Circuit.

1. Integrator Circuit. (Refer to Figure 10 for identification of switches S_a, S_b, S_c, and S_d). The operation of the Integrator is controlled by the positions of switches S_a, S_b, S_c, and S_d. Switch S_a is Q401. Switch S_b is transistor Q411. Transistors Q404, Q405, Q408, Q409, and Q410 are control circuits arranged to control the proper FET switches depending on the signals at pins 12 and 13. The integrator amplifier consists of transistors Q402 and Q403 and integrated circuit QA401. The feedback capacitor is C406. Switches S_c and S_d control the current for 9-volt zener diodes D401 and D402. Resistors R403, R404, R405, R409, R410, and R411 are full-scale calibration resistors. Potentiometers R402 and R408 are internal screwdriver calibration adjustments.

2. Zero Crossing Detector Circuit. The high gain amplifier is composed of cascaded amplifiers QA402 and QA403. Diode D411 provides a 6-volt bias supply for QA403 and the output resistor network R444 and R445. The level-splitter circuit consists of diodes D414 and D415, resistors R443 and R446 and gates QA404 (A and B).

3. Feedback Rezeroing Circuit. This circuit provides rezeroing of the Integrator circuit using negative feedback from the Zero Crossing Detector output. Transistor Q411 is the equivalent of Switch S_b in Figure 10. Resistor R434 and capacitor C414 form a feedback-loop filter circuit. Diodes D407 and D408 provide fast response for large input offsets due to input overloads.

3-6. POWER SUPPLIES.

a. ±15 Volt Supply.

1. The ±15 volt supplies tap a-c power from a secondary winding of transformer T201. Diodes D203 (A, B, C, and D) and capacitors C204, C205, C209, and C210 compose a full-wave rectifier with filtering.

2. The +15 volt regulator circuit utilizes integrated circuit QA201 which drives transistor Q206 to series regulate the output voltage. Potentiometer R209 provides calibration adjustment of the +15 volt supply. (Internal screwdriver adjustment).

3. Transistors Q211 and Q212 form a differential amplifier which compares the voltage at R218 with respect to low. The difference voltage is amplified by transistor Q210 and fed to Darlington transistor pair, Q207 and Q208, which series regulate the -15 volt output. Transistor Q209 limits the current output to approximately 200 milliamps.

b. +3.6 Volt Supply.

1. The +3.6 volt supply taps a-c power from a secondary of transformer T201. Diodes D201 and D202 and capacitor C201 form a full-wave rectifier with filtering.

2. Transistor Q205 amplifies the difference between the +3.6 output and a reference voltage derived from the +15 volt supply and determined by resistors R203 and R204. The difference voltage is amplified by transistor Q204 which drives a Darlington transistor pair, Q201 and Q202. The Darlington pair series regulates the +3.6 volt output.

3. Transistor Q203 limits the output current to about 3 amperes.

c. +210 Volt Output. The +210 volt supply is an unregulated voltage supply using the half-wave filtered voltage at diode D206 and capacitor C212.

d. +170 Volt Output.

1. Regulator. The +170 volts is derived from the +210 volts at emitter of Q302 which series regulates the +170V. Transistor Q303 provides a reference for the base of transistor Q302.

2. Blanking Circuit. This circuit controls the

+170 voltage for the three right hand readout tubes. The "Q" output of QA307B drives the base of transistor Q304 for normal regulator operation. When an overload occurs, the "Q" output is low turning off transistor Q304. This results in a drop of the +170 volt output causing blanking of the readout tubes.

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